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A REVIEW ON FREE SPACE OPTICAL COMMUNICATION

KOUSHIK SARKAR[*], SAIKAT MONDAL[**], DEBASMITA PAL[**], ABHIRUP ROY[**], RUMELA BISWAS[**]

ABSTRACT

Free Space Optical Communication (FSO) is an emerging cost-efficient method of communication which uses light pulses (mainly lasers) to transmit data. This system has the advantages of high bandwidth, high data rate of 2.5 Gbps, easy installation and license-free spectrum. In spite of many of its benefits, it is very much dependent on weather conditions and gets degraded by atmospheric turbulence and scintillation. In this paper, we have given an overview on Free Space Optical Communication by including some literature survey based on some scholarly journals. The main working principle and setup of FSO system, and its performance under atmospheric turbulence have also been discussed. Also the advantages, disadvantages, applications, current researches going on and future scope of FSO communication have been mentioned.

KEYWORDS: FSO, Atmospheric Turbulence, Bit Error Rate (BER), Bandwidth, Modulation Techniques.

INTRODUCTION

Free space optical communication is a re-emerging technology being widely used in various technologies to transport data in terms of modulated light pulses via fibre optical cables [2, 4, 6, 11-15, 19-21, 24, 25]. It uses light or laser as it's carrier, capable of optical transmission up to 2.5 Gbps and in the future 10 Gbps using WDM [3, 21, 25]. It offers a great potential for creating a three-dimensional global communications grid to transmit data between two points through any LOS propagation path to provide optical bandwidth [5, 10, 14, 17-19, 21, 24, 28, 32]. Free space means air, outer space, vacuum or something like that [11, 12, 21]. FSO links are more efficient than optical fibre or RF technologies in terms of capacity, cost, licensed spectrum, data security & rates [21, 26-28]. But they can have combined together in hybrid system as they can operate with same wavelength [20, 28, 33]. Optical wireless communication refers to transmission in unguided propagation media through the use of optical carriers [17, 22]. FSO was originally developed by NASA and was used in military purposes [28, 30, 31]. The FSO system mainly consists of two telescopes, where first part is the laser transmitter and another is the bi directional capable receiver which further connected to a high sensitivity receiver through an optical cable [14, 23].

[*]Assistant Professor, Electronics and Communication Engineering Department, Future Institute of Engineering and Management, Kolkata-700150.
[**]Student of 3rd Year ECE, Electronics and Communication Engineering Department, Future Institute of Engineering and Management, Kolkata-700150.
Correspondence E-mail Id: editor@eurekajournals.com

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The commercial FSO systems depends on low cost semiconductor laser operating in infrared region of the electromagnetic spectrum of certain wavelength [4, 26]. FSO systems should have the ability to be controlled in higher power, wide temperature ranges for long distance and assuring that mean time between failures of that system should be more than 10 years [23]. To design any FSO system some basic devices are used, there are Pseudo-Random Bit Generator, NRZ Pulse Generator, CW Laser, Mach-Zender Modulator at transmission part; while, PIN photo detector and Low Pass Bessel Filter at the receiver part. However, some of measurement tools such as BER Analyser, Electrical Power Meter are also used [14]. The advantageous part is that it typically uses intensity modulation with direct detection which is not so much complex like frequency or phase modulation [2]. However, the ever-increasing demand for bandwidth, especially for telecommunication applications, has pushed the operation of these systems to longer wavelengths, where laser diodes can provide more optical power. The FSO links involving satellites, deep-space probes, ground stations, unmanned aerial vehicles (UAVs), high altitude platforms (HAPs), aircraft and etc. [8, 11, 15]. Secure free-space optical communications have been proposed using a laser N-slit interferometer where the laser signal takes the form of an interferometric pattern. Any attempt to intercept the signal causes the collapse of the interferometric pattern [12]. Due to high carrier frequency and high bandwidth the most useful advantages of FSO link is its capability of high data rates of several Gbps [6, 7, 11, 14, 22, 25, 26]. Other several significant advantages are license-free operation, ease and speed of deployment, narrow beam width, unlicensed spectrum, commercial availability, insensitivity to electromagnetic interference, jamming or wiretapping, high SNR, cost effectiveness, low BER, less power consumption, reduced antenna size, channel and data security [6, 9, 20, 21, 22, 25, 26, 29, 30, 32]. This advantages make FSO interesting for applications like last mile problems airborne and satellite communication, temporary mobile links and permanent connections between buildings, easily deployment by saving time and cost as well as does not require any frequency authorization or any specific license [11, 13, 14, 18, 19, 27, 29]. Basically no other wireless technology is capable of this amount of bandwidth as high as FSO. It also dealing with low initial CAPEX (Capital Expenditure) requirement, intrinsic high-level data protection & security, to the good flexibility and great scalability innate in this solution [6]. Due to these reasons, FSO possible applications cover today, as mentioned, a wide range. Thus this technology generates interest in several markets: the first/last mile in dense urban areas, network access for isolated premises, high-speed LAN-to-LAN (Local Area Networks) and even chip-to-chip connections, transitional and temporary network connection, cellular backhauling, enterprise connectivity, undersea and space communication, broadband communication, storage area network, back-up link, disaster recovery among other emerging applications [6, 18, 20-23, 30, 33]. Furthermore, FSO can be used as an alternative or upgrade add-on to existing wireless technologies when the climatic conditions permit its full usage [14, 18]. Generally, FSO link can be achieved successfully for short distance and also long distance up to few kilometres link due to lower atmospheric attenuation and accurate line-of-sight link [21, 29]. But there are few successful experiment for space FSO has been achieved such as Ground-to-Orbiter Laser-com Demonstration (GOLD) , Semiconductor Laser Inter-satellite Link Experiment (SILEX)], airborne flight test system (AFTS), laser cross link system (LCS), optical communication demonstrator (OCD), stratospheric optical payload experiment (STROPEX), Mars laser communications demonstration (MLCD), airborne laser optical link (LOLA)- first demonstration of a two-way optical link between high altitude aircraft and GEO satellite (ARTEMIS) [13, 22, 24]. Those

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experiments proved the operability of long distance FSO especially from ground to space [13]. But FSO rate distance product can be increased by optical and radio frequency wireless communities, MIMO techniques, optical repetition and coherent detection [11, 15]. This FSO technology contains excellent features to be applied on the mobile military platforms. Today, FSO communication has not seen widespread use in the military [3]. With the bandwidth of FSO anywhere from 100 to 100, 000 times higher than other RF transmitters, use of FSO technology could give a military and space aviation force much leverage over their rivals [3, 6, 8, 22]. In many countries where the last mile statistics are considerably poorer is indicating a potential market for FSO technology [4, 6]. Advanced modulation techniques like orthogonal Frequency Division Multiplexing can be implemented for improving FSO transmission which is also cost effective [11]. There are so many factors are responsible for the performance degradation of this procedure like atmospheric turbulence and attenuation like cloud, rain, fog, smoke particularly over ranges of the order of 1 km or longer, aerosol scattering effects, in homogeneity in the temperature and pressure of the atmosphere that affects the refractive index of the transmission path and due to these the quality of the received signal may be deteriorated and the intensity may be fluctuated that can also leads to an increase in error probability in communication channels that can affect the bit error rate performance [2, 6, 8-10, 13-16, 18, 19, 21, 27, 30, 32, 33]. The modulation technique should be chosen according to the requirement of bandwidth or power efficiency [19]. The three most significant factors that affect the optical transmission are absorption, scattering and scintillation. Absorption is happened due to action of $C0_2$ and water vapour and scattering is caused when the wavelength collides with scatter. When the scatter size is comparable size of wavelength this is known as Mie scattering, when the scatter is smaller than the wavelength this is known as Rayleigh scattering can be calculated by beer's law and scintillation is related to atmospheric turbulence [9, 10, 16]. This scintillation degrades the link performance particularly for distances of 1 km and above [16, 33]. For weak turbulence, we can check the effect of scintillation using selection combining spatial diversity by DPSK based subcarrier intensity modulation [33]. Atmospheric turbulence can be defined by various parameters and various techniques can be used for mitigating fading according to that [2, 5, 8, 14]. To mitigate the effects of scattering and turbulence, multiple transmitters and receivers can be used. Hence, it would be possible to benefit from spatial diversity and receive multiple independent copies of the same signal [5].More recently, the error rate performance comparison of the coherent and subcarrier intensity modulated optical wireless communications was analysed in [15]. In conventional radio frequency technology, the cooperative diversity is studied that can be applied to FSO technology [15]. By the probabilistic and statistical representation of turbulence, the character and reliability can be proved of a FSO link [10]. We can include relay assisted technology to realise the help of MIMO technique and further we can evaluate the performance of that specific FSO system and also we can exploit multiuser diversity to avoid turbulence problems and fluctuations [15]. Under different atmospheric factors the correct propagation wavelength should be chosen studying the Q factor, minimum BER and eye diagram [27]. Due to unguided narrow beam propagation through free space, there is another problem occurred involves PAT (pointing, acquisition, and tracking) technique [30]. Last but not the least, compared to a microwave link, an FSO link can support higher bit rates and its operational frequencies are license-free in all jurisdictions apart for a year low cost fee that must be paid to the reference Public Administration [6]. According to Edholm's law, "The demand for point-to-point bandwidth in

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wireless short-range communications has doubled every 18 months over the last 25 years. It can be predicted that data rates of around 510 Gb/s will be required in ten years." [31]. Free space optics is a technology that is poised for exponential growth in the coming future.

LITERATURE SURVEY

Cryptography allows communication between two people undetectable by a third person, which requires a cryptographic key. Quantum Key Distribution (QKD) is one of the best processes which use single-photon communications to generate security keys, and can be transferred to kilometre-scale distances during both day and night. The transmitter sends a sequence of random bits, which are randomly encoded as linearly polarized single photons either in horizontal or vertical polarization. The receiver randomly analyses the polarization, detects any third party and forms the key, and the communication is secret and error-free [1].

Atmospheric turbulence is one of the biggest challenges for free-space optical communication as it degrades the optical links in kilometre ranges. As the receiver aperture cannot always be greater than the correlation length of intensity fluctuations, and the observational time can be less than the correlation time, the signal fading has to be reduced under this condition. One method of reducing turbulence-induced fading is Maximum Likelihood Sequence Detection (MLSD) technique [2].

Free space optics can also be applied in military mobile communication. Until 1980s, it has been a problem to use FSO and laser technology in military due to low capacity. Though not applied widely, but FSO can be used in military due to high bandwidth, security, reduced bit error rate, low signal attenuation and power consumption [3].

FSO is used in metropolitan area networks (MAN) due to high bandwidth and data rate, and low cost, by increasing the capability of laser diodes. In Brazil, there is an enormous market of Free Space Optical communication, but depends on the atmospheric conditions of different zones, and the corresponding performance. Accordingly, the distance and availability of connection would vary, but is very efficient [4].

Free space optical communication is the only efficient technology for three dimensional global communications between ground and air, due to its advantages. To overcome atmospheric turbulence problems, necessary measures can be taken, such as using multiple transmitters and receivers, i.e., Multiple Input Multiple Output (MIMO) systems. It would then be possible to get multiple independent copies of the same signal. MIMO optical communication systems can overcome both amplitude and phase distortions [5].

Free space optics or Laser communication had been first developed for defence applications, and now used for both military and civilian purpose due to high bandwidth, speed, easy installation, cost effectiveness, license-free operation and other advantages. Applications of FSO had been started and became popular since the early 90s. The first implementation of FSO was done using ruby laser technology. FSO has some limitations due to weather effects, but can be reduced by taking necessary measures [6].

Many researches and developments have been done on FSO communications other than conventional FSO systems, and new systems have been made, such as in Japan, by making the wavelength same as that of fibre optics systems for large transmissions. Also high speed broadband connection is provided using low transmission power, by decreasing the diffraction of laser beams, and wavelength multiplexing techniques. Improvements are being made to

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mitigate problems due to atmospheric disturbances [7].

Satellite links, ground stations, unmanned aerial vehicles (UAVs), etc., demands free space optical communication. But due to the problems of this system, a designer need to know the challenges of FSO systems. Those are: modulation schemes, atmospheric disturbances and error protection schemes. If these points are taken care of, FSO communication has good prospects for practical field [8].

BER (Bit Error Rate) of received data changes proportionally with path length, data rate and divergence angle. Q factor changes inversely with distance and divergence angle. FSO system basic design has implemented and simulated for performance characterization by using a powerful software design tool named Optsim 4.6 which is which enables to test, plan and simulate maximum type of optical link [9].

A proposal is given to calculate and measure the symbol error probability under different type of channels used in FSO system for the turbulence channel models such as the Rayleigh, Log-normal, Gamma-gamma. Beside this, Negative exponential model distribution is valid from weak to strong turbulence regime. Rayleigh model has a much higher density in the low amplitude region. The Gamma-gamma model performs better than any other model, for all regimes from weak to strong turbulence region [10].

Free Space Optics is additionally used for spacecraft communications. The stability and quality of the terrestrial link is highly dependent on atmospheric factors such as fog, haze, rain, snow and heat. Free space optical (FSO) communications is also called as a line- of-sight (LOS) technology that produces a modulated beam of visible or infrared light to the receiver for broadband communications. The transmission through FSO is fast as the speed of light [11].

The FSO is often used for digital communication systems because of its easy infrastructure, security and low cost, but the performance of FSO is very sensitive to the medium. Infrared Data Association (IrDA) technology is a part of FSO communications. The DPSK format has a better performance than OOK & PSK in atmosphere turbulence and other conditions for its much longer symbol distance, this format will be implemented in future [12].

The losses are summation from all kind of attenuation, that is geometrical attenuation, absorption, scintillation and rain attenuation or haze attenuation. In tropical region, rain becomes a dominant factor of attenuation which cause poor signal or even lost the communication. Haze particles are calculated under Mie Scattering effect and the main variable to measure haze attenuation is visibility range [13].

FSO communication has few limitations also like weather effect (clear weather, rain, snow, fog etc.), beam dispersion, scintillation etc. It is very clear as we move from clear weather to heavy fog Q factor will decrease as well as the transmission factor. If there is rainy weather, then attenuation does not occur that much, but it affects the transmission range of FSO. Where weather conditions like snow and fog FSO's transmission range becomes very less due to increase in the attenuation [14].

The distance-dependent atmospheric turbulence and path-loss affect vast use of FSO systems and decrease their utility to short-range links. To overcome this, log normal distribution, gamma-gamma distribution, weak turbulence condition, strong turbulence condition, outage probability analysis, BER analysis, average capacity analysis, diversity order analysis models are implemented [15].

FSO links faces problem due to atmospheric turbulence because of in homogeneities in the index of refraction known as scintillation as a result of stochastic amplitude fluctuations.

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Different factors that affect the communication channel in FSO communication system is presented with different channel model such as Rayleigh, Rice and Nakagami models. The parameters which control performance, are outage probability and bit error rate (BER) [16].

Optical wireless communication which operates near infrared (IR) band is termed as Free Space Optical (FSO) Communication. It is widely used for high rate communication between two fixed points over distances up to several kilometres. Despite of several advantages of FSO like video surveillance and monitoring, security, broadcasting, redundant link and disaster recovery, back-haul for cellular system etc., the widespread use of FSO has been affected by its disappointing link reliability especially in long ranges due to atmospheric turbulence-induced fading and sensitivity to weather conditions [17].

In recent days, telecommunication and computer networking are moving towards optical communication as light is the fastest medium which can transport huge information's, cost effective, flexible etc.FSO is employed as an alternative solution to broadband short distance applications. Total attenuation influencing FSO systems depends on two factors-scattering loses and geometric loss etc. Geometric loss increases with the increase of link range, divergence angle, transmitter aperture and decreases with increase in receiver aperture diameter. Effect of rainfall on FSO system is negligible. Total attenuation increases with increment of distance link, low visibility and with decrement of wavelength [18].

FSO are affected by weather conditions like fog precipitation. Transmitted optical signals arrive at the receiver are converted to electronic signals by photo detectors. Photodiodes are widely used in optical communication for its small size, suitable material, high sensitivity and fast response time. Bit Error Rate (BER) is the second feature of FSO communication system [19].

Cellular backhaul consists of connections between base stations and the core network components. The necessity for upgrading backhaul and increasing its capacity is growing rapidly with the increase of high speed data services and network densification using small cells. Presently three transport media are used for backhaul solutions: copper (about 90%), microwave radio links (about 6%) and optical fibres (about 4%).Radio frequency technologies have been widely studied for backhauling nut they are much more prone to weather conditions. FSO beam has a wavelength in micrometre range. When two FSO nodes are not in line mirror is place at a third node which provides connectivity [20].

FSO works on The Line of Sight a phenomenon which consists of LASER at source and detector at the destination that provides optical wireless communication between them. At the receiver side the signal is de-multiplexed buy 1x4WDM de-multiplexer in order to generate on too many combinations. Signals are demodulated by photo detectors. To measure SNR electric power meter is used at receiving end [21].

FSO communication provides LOS communication as it has narrow bandwidth and operates in visible and IR spectrum. Though FSO system is vulnerable to various atmospheric phenomena so methods have been implemented to combat such situations [22].

Several techniques are implemented to enhance the performance of FSO systems: a) Performance of SAC OCDMA based FSO System-Spectral Amplitude Coding Optical Code Division Multiple Access technique is used as it has certain advantages like flexibility of channel allocation, asynchronously operative ability, privacy enhancement and network capacity increment. b) High Speed, Long Reach OFDM-FSO transmission link incorporating OSSB and OTSB scheme-By introducing this scheme an effort had been made to examine the impact of

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environmental conditions and to design a high speed FSO system [23].

"Link Margin" is described by the performance of a FSO system that is the ratio of the received signal power to the signal power required to achieve a given data rate with acceptable Bit Error Rate. Outrage Probability represents the probability of decreasing the instantaneous SNR at the input of the receiver below the threshold [24].

FSO system transports data means the modulated light pulses via laser and LOS technology through fibre optics that enables transmission up to 2.5 GBPS of data. This cost effective, easily upgradable technology can be used in various applications like in military, space aviation, last mile access, enterprise connection etc. FSO with massive bandwidth, can be maintained by four types of topologies: point-to-point, point-to-multipoint, a mesh, and a ring. Though it has some concerns for atmosphere but is poised for exponential growth in the coming years [25].

FSO provides larger bandwidth, easily deployment, higher mobility-data security-carrier frequency, good data rates than RF and other wireless technologies for both short and long range communication. Rather than many drawbacks due to the atmospheric turbulence like scattering, absorption etc. which can be avoided in upper troposphere transmission, it is used for many applications like in enterprise connectivity, video surveillance, back haul for cellular systems, broadcasting etc. and also includes last mile technology [26].

For licence free bands, robustness, high data rate, bandwidth &security and negligible signals interference, FSO is best suited for multi GBPS data rate communication with only drawback of atmospheric attenuation. The FSO link can be investigated by BER analysis and output of spectrum analyser under different atmospheric conditions and we can choose the proper wavelength of the optical transmission window comparing some factors like propagation distance, BER, Q factor and height of eye [27].

FSO and RF can be used independently as well as in combination at certain places to increase the efficiency of the system due to the non-interference between them. The FSO can be compared with RF technology in terms of data rate, efficiency, data security, frequency band allocations, distance, performance at atmospheric turbulence, capacity and limitations. The drawbacks of both systems can be compensated by the hybrid system [28].

FSO works by modulating radio subcarriers over an optical carrier can achieve higher data rates. Different modulation formats like NRZ and RZ can be used with different photodiodes APD and PIN for different wavelengths to compare them with each other in terms of Q factor. The main challenge for FSO is atmospheric attenuation that can be calculated by KRUZE'S and KIM'S model [29].

The range of the applications of FSO is extensive, from home to satellite as it is licence-free, provides high bandwidth, data rates and consume less power though it has some disturbances of atmospheric turbulence, channel modelling, transport layer issue and PAT (Pointing, Acquisition, & Tracking). It can be classified into three optical wireless networks: (i) satellite (ii) terrestrial (iii) home. The FSO networks can be designed using channel characterization, link availability and reliability, automation, network topology, quality of service, link cost & eye safety [30].

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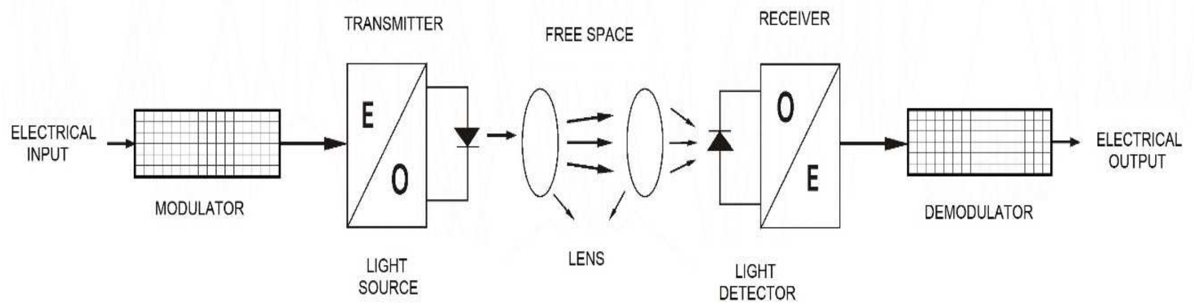

Figure 1.Block diagram of an optical wireless link showing the front end of an optical transmitter & receiver (https://www.intechopen.com/books/contemporary-issues-in-wireless-communications/ free-space-optical-communications-theory-and-practices[Ref.38])

By using WLS fibre, omnidirectional OWC system can be designed through the broadband emission and omnidirectional direction in RF wireless systems. Through this type of FSO, lasers in the visible region can be transmitted in water with low attenuation and high bit rate transmission capabilities that will help as communication system for underwater tele operation mining equipment by some process like optical detection, amplification, photon detection and selection of photodetectors [31].

FSO is a transmission system between transmitter and receiver by a LOS path can be used in many transmissions for its high bandwidth, data rates, data security, spectrum licensing with some drawbacks of atmospheric effects. It is designed for the long range communication applicable in military and etc. but can serve short range purpose if tie-ups with RF technology. FSO is the last mile solution in critical situations for immediate connectivity [32].

FSO system can be evaluated by an expression of probability distribution function analysing BER of subcarrier intensity modulation using DPSK for weak atmospheric turbulence. After combining and changing the selection combining spatial and temporal diversity as a possible means of circumventing the effects of scintillation, the link margin with two photodetectors can be checked by comparing the SNR and CSI for different turbulences and diversity [33].

BASICS OF WORKING AND RELEVANT DISCUSSIONS WORKING PRINCIPLE

Free Space Optical (FSO) communication offers a great potential for creating a three dimensional global communications grid [5]. It transmits the information in modulated light pulse form through the optical fibres or laser light through an atmospheric channel in mainly troposphere. FSO is basically relied on infrared light, this communication process is safe from electromagnetic interferences, jamming or wiretapping [6]. This system mainly consists of two telescopes, where first part is an optical transceiver with a laser transmitter and another is the bi directional capable receiver which further connected to a high sensitivity receiver through an optical cable. The optical transmitter systems are criticized in terms of size, power, and beam quality, which determine laser intensity and minimum divergence obtainable from the system. The transmitter is a combined form of an optical source, a modulator, an optical amplifier and beam forming optics. [17]. At the receiver, the field is optically collected and detected, generally in the presence of noise interference, signal distortion and background radiation. On the receiver side, important features are the aperture size and the focus number, which determine the amount of the collected light and the detector field-of-view [16].

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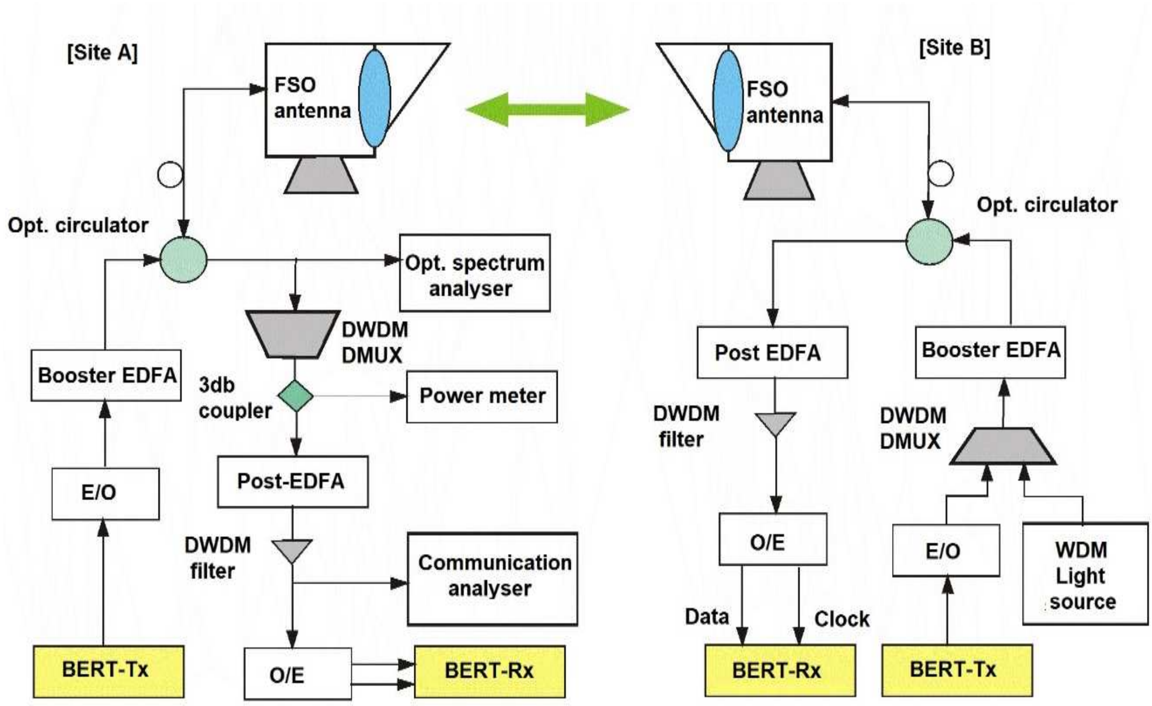

Figure 2.System design of Transceiver of FSO (https://www.intechopen.com/source/html/39677/media/image50_w.jpg[Ref. 40])

For a pair of optical transmitter and receiver, the power balance concept is used to establish the maximum distance of operation or link range and characterised the FSO system:

Power balance = P (0)-P(R) - α

where P (0) represents the average power at the transmitter output (dBm), P(R) represents the receiver sensitivity (dBm), and α represents the total loss on the free space link (dB).

Transmission using FSO is very simple as it uses a low power lasers and the telescoped to transmit wavelengths through the air to a receiver. At the source, the visible or IR energy is modulated with the data to be transmitted. At the destination, the beam is intercepted by a PIN photodetector, the data is extracted from the visible or IR beam means demodulated, and the resulting signal is amplified and sent to the hardware. If the energy source does not produce a sufficiently parallel beam to travel the required distance, collimation can be done with optical lenses [25].

For any transmission, first we have to choose the medium and the characteristics of the wave which is going to pass through the medium [5]. A commonly used model defines that the mediums can be varied in terms of individual cells of air of different diameters and refractive indices [10]. The optical carrier typically laser is transmitted as an optical field through an atmospheric channel [16]. Lasers operated in the infrared, visible and UV regions of the electromagnetic spectrum from 1 mm down to 100 nm in wavelength. Laser is characterised in terms of wavelength and it is so beneficial to use laser as the communication medium [3]. In the time of propagation, the laser beam is attenuated by some atmospheric turbulence and the path loss is occurred due to error, which can be measured by the Friis transmission equation:

$$P_R = P_T n_T n_R G_T G_R \left(\frac{\lambda}{4\pi l}\right)^2 h = Ah$$

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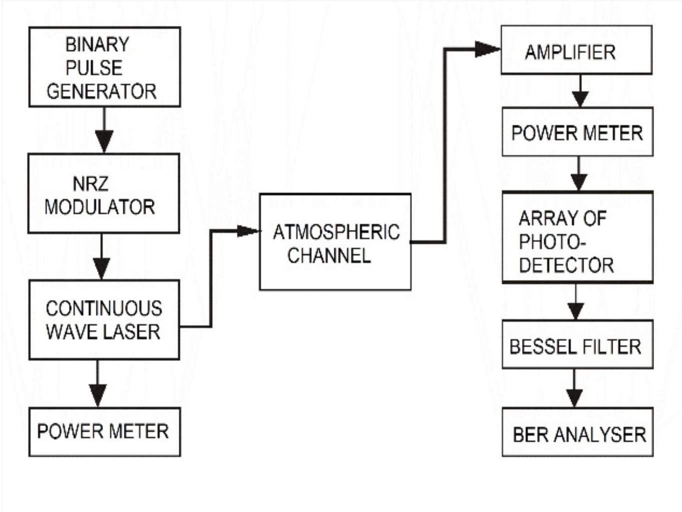

Figure 3.Transmitter-Receiver block diagram of FSO (https://www.degruyter.com/view/j/joc.ahead-of-print/joc-2016-0064/graphic/joc-2016-0064_figure1.jpg[Ref.39])

Where, P_T, n_T, G_T are the optical power, efficiency, and telescope gain of the transmitter and P_R, n_R, G_R of the receiver, respectively. h is the channel state, computed by $h = (h_l)x(h_a)x(h_p)$ where h_l, h_a, h_p represent the atmospheric attenuation, the atmospheric turbulence and pointing errors, respectively [20].

Now, we have to characterize the proposed channels. Several probability density functions have been used for the intensity variations at the receiver of an optical link. The atmospheric turbulence affects the performance of an FSO link by causing the received optical signal to vary randomly thus giving rise to signal fading. The fading strength depends on the link length, the wavelength of the optical radiation and the refractive index structure parameter Cn^2 of the channel.

RAYLEIGH DISTRIBUTION

The Rayleigh model is used to describe the channel gain. The scintillation index for the Rayleigh situation is The density function of Rayleigh is more concentrated at low(deeply faded) values. The PDF for Rayleigh distribution is:

$$f(I) = \frac{I}{\sigma_R^2} exp\left\{-\frac{I}{2\sigma_R^2}\right\}, I \geq 0$$

LOGNORMAL DISTRIBUTION

The log-normal models assume the log intensity l of the laser light traversing the turbulent atmosphere to be normally distributed with a mean value of -l 2/2.Thus the probability density function of the received irradiance is given by:

$$f(I) = \frac{1}{(2\pi\sigma_R^2)^{\frac{1}{2}} I} exp\left\{-\frac{\left(\ln\left(\frac{I}{I_0}\right) + \frac{\sigma_R^2}{2}\right)^2}{2\sigma_R^2}\right\}$$

Where, I represent the irradiance at the receiver and Io is the signal irradiance without scintillation.

GAMMA-GAMMA DISTRIBUTION

Al-Habash et al. proposed a statistical model that factorizes the irradiance as the product of two independent random processes each with a Gamma PDF. The PDF of the intensity fluctuation is given by:

$$f(I) = \frac{2(\alpha\beta)^{\frac{\alpha+\beta}{2}}}{\Gamma(\alpha)\Gamma(\beta)} I^{\frac{(\alpha+\beta)}{2}-1} K_{(\alpha-\beta)}\left(2\sqrt{\alpha\beta I}\right), I \geq 0$$

I is the signal intensity, gamma (.) is the gamma function, and $\dot{k}_{\alpha\beta}$ is the modified Bessel function of the second kind and order $\breve{\alpha}\beta$. α and β are PDF parameters describing the scintillation experienced by plane waves [10].

NEGATIVE EXPONENTIAL MODEL

When very strong turbulences approached, then the scattering is increased with increasing link length. Then the fluctuations of the optical beam normally indicate negative exponential statistics:

$$f(I) = {}^{I}/_{I_0} \exp\left(-{}^{I}/_{I_0}\right), I$$

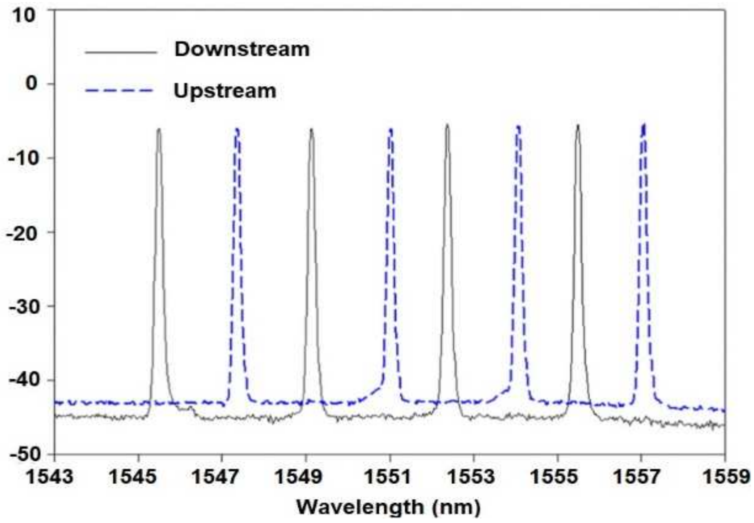

Figure 4.Downstream and Upstream attenuation for different wavelength (http://ieeexplore.ieee.org/ mediastore/IEEE/content/media/4563994/7305892/7293590/yu6-2488286-large.gif[Ref.41])

Where, Io indicates the mean received irradiance and I is the irradiance [24].

Then we have to decide about the modulation technique. The optical carrier can be modulated in its frequency, amplitude, phase and polarization. Generally, either amplitude modulation is used with direct detection or phase modulation is used with a homodyne or heterodyne receiver. The technically simplest digital modulation scheme is amplitude shift keying. In optical systems, it is known as on-off keying (OOK) where light source means carrier is turned on to transmit logic 1 and turned off for logic 0. NRZ (non-return to zero) and RZ (return to zero) are different types of modulation where RZ is more sensitive. For OOK, the exact wavelength of the carrier and its phase are irrelevant for the demodulation. The receiver just directly detects the currently incoming power and compares it against a certain level. Coherent modulation systems are also used in optical communications. Usually, a binary coherent modulation scheme is used [8]. In any atmospheric channel, there are two independent phenomena: scattering and turbulence induced scintillation. We have to analyse the attributes of those factors to the system impulse response mathematically based on some assumptions [5]. Basically an OOK system is sturdier than coherent system in terms of atmospheric turbulence because for OOK the information is only encoded in intensity whereas the PSK uses both intensity and phase. Both intensity and phase is get distorted due to atmospheric turbulence. It is mainly used in optical fibre communication for its low complexity [8].

The wavelength selection is also an important part for link performance and detector sensitivity. It depends on the atmospheric effects and the background noise power. As antenna gain is inversely proportional to the wavelength so lower operating wavelength is more beneficial but higher wavelength gives better link quality and lower pointing induced signal fades. So the wavelength should be chosen carefully according to the FSO system [22].

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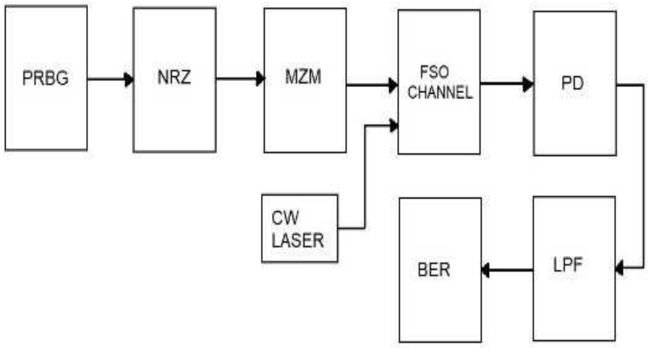

Figure 5.Block diagram of basic concept of typical system design of FSO [14]

The next part is the designing of the FSO system according to the medium and modulation techniques using the basic concepts and devices. As mentioned earlier, there are two sections for the FSO system, those are (i) transmission part and (ii) receiver part. There are Pseudo-Random Bit or binary sequence Generator, NRZ Pulse Generator, CW Laser, Mach-Zender Modulator at transmission part; while, PIN photo detector and Low Pass Bessel Filter at the receiver part.

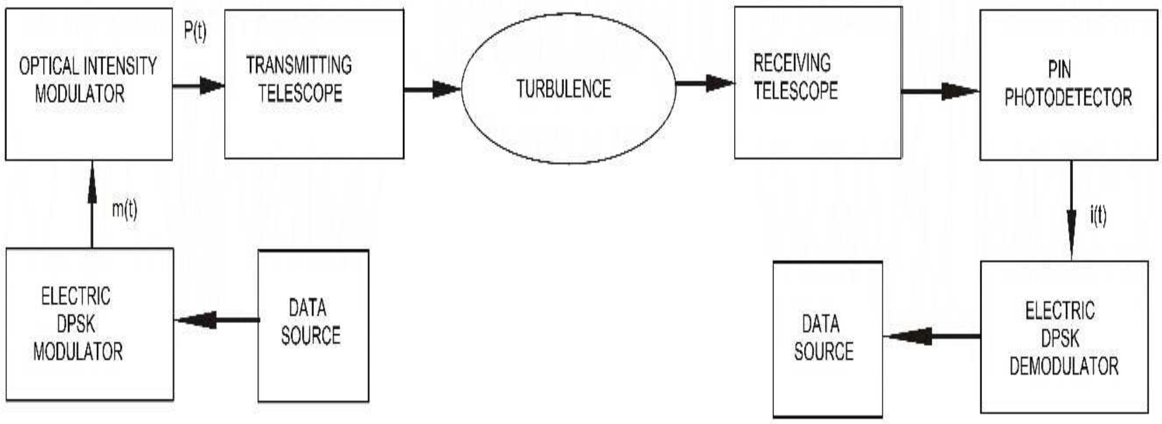

Figure 6.Block diagram of occurrence of turbulence between transmitter and receiver (https://www.spiedigitallibrary.org/ContentImages/Journals/OPEGAR/54/10/106109/FigureImages/OE_54_10_106109_f001.png[Ref.42])

There are also some measurement parts such as: BER Analyser, Electrical Power Meter are used as well. Pseudo random bit generator which generates the logical signals means a sequence of 1's (ON) OR 0's (OFF) and transmits to the NRZ pulse generator. The function of the NRZ pulse generator is to encode the logical signal into the electrical signal and to further pass this signal to the Mach-Zender Modulator. This modulator receives two inputs i.e. electrical signal from the NRZ pulse generator and other is from continuous wave laser as a carrier signal. The primary function of this modulator is to convert the electrical signal into the optical signal because the system is working on the free space optics. Now this modulator passes the optical signal with carrier signal to the photo-detector via a medium called FSO channel. Another part of the transmitter is direct modulated lasers based on InGa As semiconductor technology with operating wavelengths around 1550 nm were developed specifically for fibre optic attenuation characteristics of optical fibre in this wavelength range. Photo-detector further converts the received optical signal again in the electrical form and passes it to the low pass filter. Thus the signal is got filtered to remove the unwanted desired electrical signal. The error occurred and the power can be measured by BER analyser and electrical power meter respectively [9, 14]. In

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laboratory, the OFDM modulator is used for FSO, which is implemented with 256 parallel data streams with an aggregate bit rate of 10 Gb/s, which are subsequently mapped onto N baseband QPSK constellations prior to becoming a input into the N-point inverse Fast Fourier Transform [11]. Also a DPSK generator which is formed by the cascading of the amplitude and phase modulator & the drive signal of the phase modulator is preceded by a delay-XOR pre-coder to form the differentially encoded data sequence. Then the channel is formed by performing the noise, scintillation & fading. Then an asymmetric Mach-Zender interferometer splits the signal to two paths and recombines these two signals after a path difference corresponding to the symbol duration. A balance receiver follows the interferometer as a multiplier to demodulate the differentially coded signal [12]. To evaluate the performance of the transmission in a FSO system, by the terms link margin and link availability. Link margin determines the extra power available in a link after any transmission, can be calculated by the formula:

$$M_{link}\,(dB) = P_t - S_r - A_{Geo} - A_{scin} - A_{haze} - A_s - A_{rain} - A_{system}$$

It is determined by subtracting all losses that occur during data transmission including receiver sensitivity, S_r (dBm) by optical transmit power, P_t (dBm). The losses

containing the losses from atmosphere which are absorption, A_s (dB), scintillation, A_{scin} (dB), rain attenuation, A_{rain} (dB) and haze attenuation, A_{haze} (dB) as well as the losses from the system itself, A_{system} (dB) and geometrical attenuation, A_{Geo} (dB). Receiver sensitivity is the minimum amount of optical energy that must be received by the FSO system for a specified error rate [13].

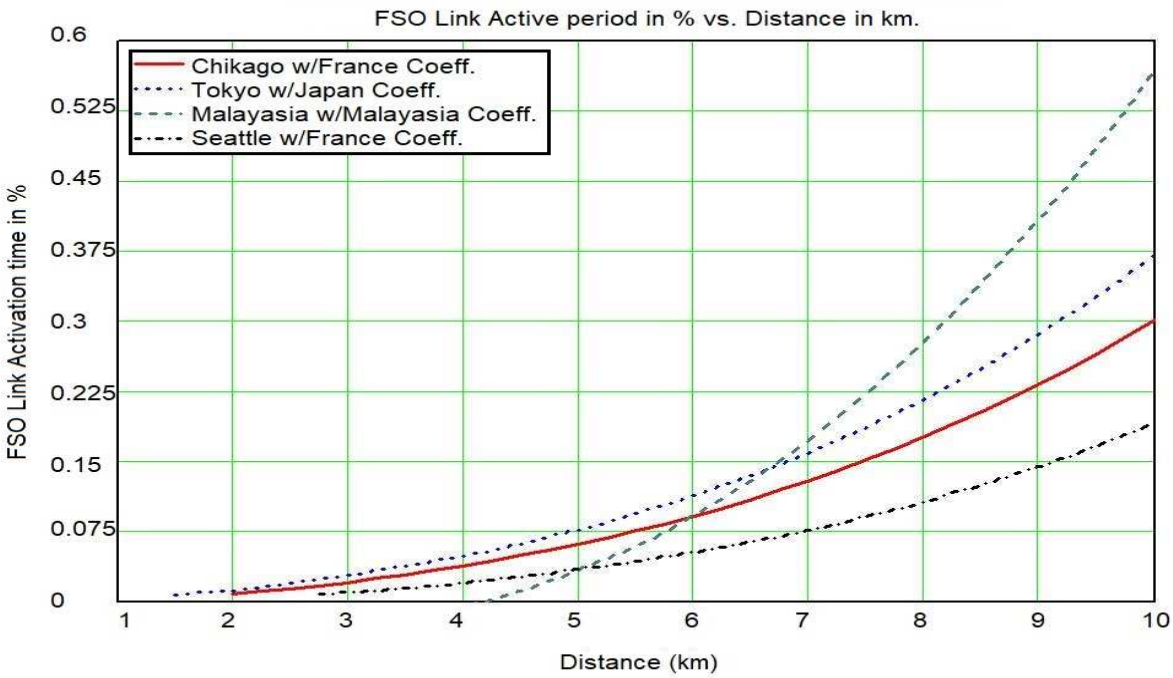

Figure 7.Distance vs. Link Activation graph (http://spectranetllc.com/wp-content/uploads/2014/10/Hybrid_percent_of_time.jpg [Ref.43])

Now we are going to discuss the working principle of FSO in presence of different atmospheric attenuation and turbulence because it is one of the main and constant problem for this system. For First we have to study the theories used to model like KRUZE's model, KIM's model etc. atmospheric turbulences and attenuations. Now for atmospheric attenuations like fog, smoke, rain etc. we have to calculate some parameters related to that and after that

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we have to mitigate those attenuation factors for better transmission. Then for turbulence, we have to derive the spatial and temporal coherency of the optical field and finally the selection combined spatial and temporal distribution of turbulence induced fading.

ATMOSPHERIC ATTENUATION

The interaction of laser beam with the air molecules and aerosols results the attenuation. Power of the optical beam maintains an exponential decay as the propagation distance increases according to the formula of optical transmission τ:

$$\tau = \tau_a + \tau_s = \frac{P(l)}{P(0)} = \exp\left(-a * l\right)$$

Where, l is the propagation is the distance and a is the overall attenuation coefficient, can be determined by four different processes: molecular absorption, molecular scattering, aerosol absorption and aerosol scattering. [6]

ABSORPTION

Absorption is caused by the photon of laser beam colliding with different finely dispersed liquid, solid particles in the air like dust, water vapour etc. and the aerosols like water, O_2, O_3 and CO_2 at infrared wavelengths. The absorption coefficient (β_{abs}) dependent of temperature and pressure can be calculated from:

$$\beta_{abs} = \alpha_{abs} * N_{abs}$$

Where, α_{abs} is the effective cross section and N_{abs} is the concentration of the absorption particles. [13, 18]

SCATTERING

When a beam of radiation is dispersed into a range of directions a physical interaction occurred and that is called scattering. When a particle accidentally intercepts an electromagnetic wave, then a part of the energy of that wave is removed and re-radiated into a solid angle at the centre. There is energy loss for that particle. The scattering can be categorized into three types: (a) Rayleigh or molecular scattering (b) Mie or aerosols scattering i.e. haze, smoke and (c) Non selective scattering i.e. rain. The coefficient of scattering (β_{scat}) can be calculated by effective cross section (α_{scat}) and concentration (N_{scat}) of the particle as:

$$\beta_{scat} = \alpha_{scat} * N_{scat}$$

The atmospheric attenuation can be happened due to some different factors like haze, rain, or fog etc. by scattering or absorption. [13, 18]

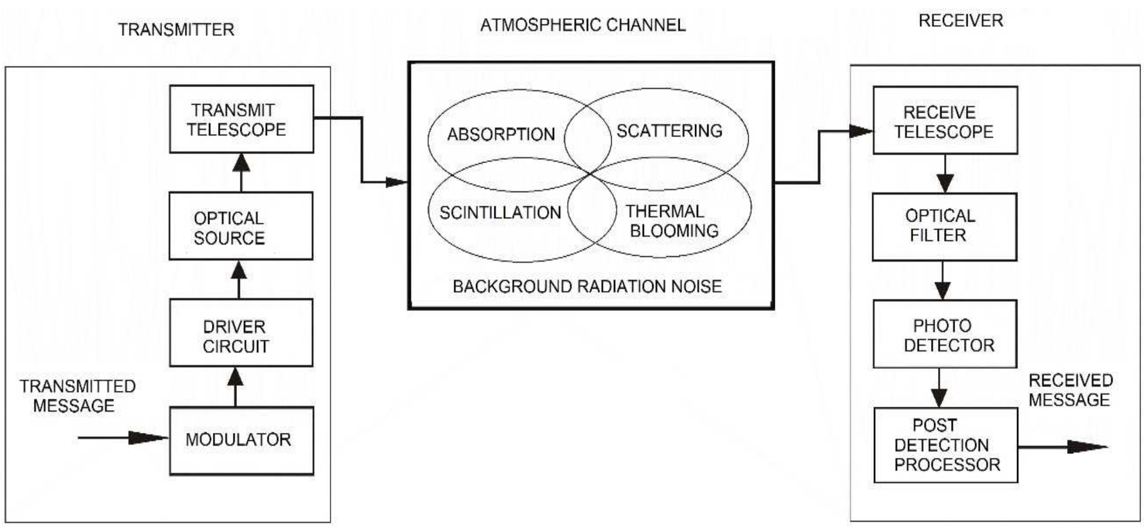

Figure 8.Terrestrial FSO Block Diagram (http://slideplayer.com/slide/8200855/25/images/7/Terrestrial+FSO+Block+Diagram.jpg [Ref.44])

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RAIN ATTENUATION

Water vapour contained in atmosphere form the rain. So the radius of the raindrops is larger than the wavelength of the FSO system and non-selective scattering is occurred due to rainfall. The rain scattering coefficient ($\beta_{rain\,scat}$)can be calculated as follows:

$$\beta_{rain\,scat} = \pi a^2 N_a Q_{scat}\left(\frac{a}{\lambda}\right)$$

Where, ais the radius of raindrop, N_a is the raindrop distribution and Q_{sat} is the scattering efficiency. [13]

HAZE ATTENUATION

Particulate matters from smoke, dust, gaseous pollutants etc. occurs this type of attenuation which is a type of Mie scattering. It can be portrayed and calculated by:

$$A_{haze} = 10\log_{10} exp^{\left[\frac{3.91}{V}*\left(\frac{\lambda}{550\,nm}\right)^{-q}*L\right]}$$

Here, A_{haze} is the attenuation coefficient, λ is the wavelength, V is the volume of the particle, L is the propagation distance and q is dependent of particle size distribution. [13]

ATMOSPHERIC TURBULENCE

When air parcels at different temperature are combined with wind and convection, then turbulence occurred that affect the propagation of optical beam of any FSO system. This situation results to sudden change in density and refractive index by both spatial and temporal coherencies. Generally, scale of turbulence cells is larger than beam diameter but when the same is smaller than beam diameter then scintillation occurred [6, 18].

SCINTILLATION

It is basically the beam intensity fluctuations when the scale of turbulence cells is smaller than the beam diameter caused by the change in refractive index of the atmosphere of the propagation path. It is one of the most noticeable one for any FSO system depends on the weather of the day. The strength of this can be calculated by σ_i^2:

$$\sigma_i^2 = 1.23 * C_n^2 * k^{7/6} * L^{11/6}$$

Where, $C_n^2$is the refractive index structure, k is the wave number and L is the link range.

There are some features are present to define

the performance of any FSO system, are signal to noise ratio (SNR), bit error rate (BER) and outrage probability except link margin and link availability. In receiver section, PIN photodiode is present to convert the transmitted signal to electrical signal, where the S/N ratio is given by:

$$SNR = \frac{I_p^2}{2_q B(I_p + I_D) + 4KTBF_n\,/R_L}$$

Where I_p is the average photocurrent, q is the charge of an electron(C), B represents the bandwidth, I_D is the dark current, T is the absolute photodiode temperature (K), F_n is the photodiode figure noise equal to 1 for PIN photodiode, R_L is the PIN load resistor. Outrage probability is another term used for any wireless communication link that describe the probability of unavailability of the communication link.It represents the probability of decreasing the instantaneous SNR at the input of the receiver below the threshold. The receiver's threshold depends on the sensitivity limit of the detector. The outage probability is given by:

$$P_{Out} = P(\gamma \le \gamma_{th})$$

Generally, NRZ-OOK type of modulation is used for FSO. The relation between BER and SNR is [19]:

$$BER_{NRZ-OOK} = \frac{1}{2} erfc\left(\frac{1}{2\sqrt{2}}\sqrt{SNR}\right)$$

$$Mathematically, BER = \frac{Number\ of\ Errors}{Total\ number\ of\ bits\ sent}$$

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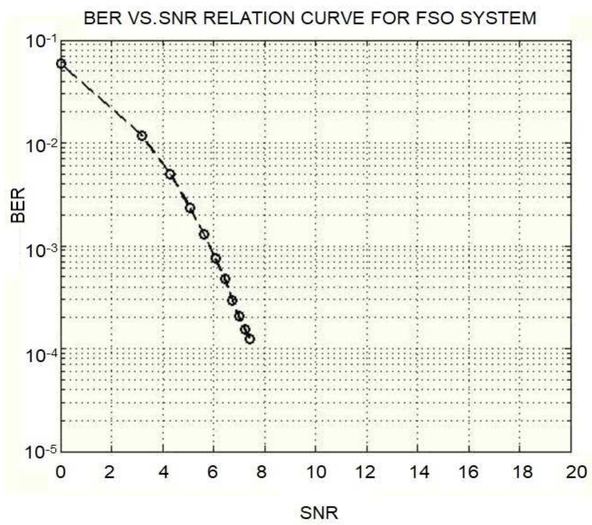

Figure 9.BER vs. SNR plot for BPSK using OFDM-FSO system (https://ai2-s2-public.s3.amazonaws.com/ figures/ 2017-08-08/8dac610e935e499c828da6f006a6fced57d527a1/3-Figure1-1.png[Ref.45])

The FSO system performance can be checked in terms of link margin which can be calculated from link equation. It measures all link degradations and gains including transmit power to determine the received signal level. Thus the link margin is calculated by comparing the received signal level with the sensitivity of the receiver. When the channel is atmospheric disturbance, the link equation for transmit power will be:

$$P_{RX} = P_{TX} \, . G_{TX} \, . G_r \, . G_{RX} \, . A_{system,lin}$$

For this system the performance can be determined directly from the power transmitted. The signal power received P_{RX} depends on the transmit power P_{TX}, transmit antenna gain G_{TX} receive antenna gain G_{RX}, the range loss Gr, and system-dependent losses A system, lin. When the signal is disturbed because of extinction by air molecules or aerosols. The transmittance T of laser radiation that has transmitted over a distance L is described by the Beer's law:

$$T = \exp\,[-\alpha_e(\lambda) \, . L\,]$$

Where the αe(λ) is the positive extinction co-efficient defines the extinction level of the medium and L is the distance for the transmission [8].

Though there are so many disturbances due to atmospheric turbulence, but the system performance can be enhanced using various techniques:

1. Spectral Amplitude Coding Optical Code Division Multiple Access technique is used in FSO system. This multiplexing scheme has several advantages like flexibility of channel allocation, asynchronously operative ability, privacy enhancement, and network capacity increment.
2. High Speed, Long Reach OFDM-FSO Transmission Link Incorporating OSSB and OTSB Schemes. In the OFDM scheme, an effort has been made to probe the impact of the environment conditions and to design a high speed and long reach FSO system free from the multipath fading. Different atmospheric conditions channels are used to model different types of condition in system.
3. Optimization of Free Space Optics Parameters Using WDM System. A unidirectional WDM system can be designed. Different characteristics like data rate, power, link range, number of users, and channel spacing are needed to be optimized according to the weather conditions [23].

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ADVANTAGES

1. Free space optical communication allows secured communication between the transmitter and receiver, undetectable by any third party, due to spatial confinement between laser beams and low beam divergence, and also reduces power loss and consumption [1, 5, 8, 9, 10, 12, 14, 17, 19, 22, 23, 26, 27, 28, 30-32].
2. FSO communication has range in kilometer-scales, about 150km [1, 3, 14, 18, 25].
3. Communication is possible in both daylight and dark by taking suitable measures [1].
4. Free space optics use intensity modulation and On-Off Keying (OOK), which is better than transmitting RF signals using analog modulation [2, 11, 17, 20, 27].
5. Data rate of about 2.5 Gbps is achieved using free space optics and can be extended to 40-200 Gbps, using Wavelength Division Multiplexing (WDM). Also bit error rate is reduced to 10^-9 range [3, 6, 11, 13-32].
6. Bandwidth availability of 100 to 100000 times higher than radio frequency signals are provided by FSO technology, and also uses high carrier frequency of 300THz [3, 5, 6, 8, 10, 11, 14, 16, 17, 19, 21-25, 29, 31, 32, 33].
7. FSO system is very simple and cost effective and installation is easier than many other systems like fiber-optics links, and cost is reduced using modulation techniques like Orthogonal Frequency Division Multiplexing [4, 6, 9, 10, 11, 12, 14, 15, 16, 19, 20, 21, 22, 24, 25, 26, 27, 29, 31].
8. The optical power provided by FSO systems can be increased by modifying the laser diodes to increase the wavelength, and other improvised designing [4, 30].
9. Free Space Optical communication is the only effective way to implement a three-dimensional communication grid between ground and airborne nodes [5, 20, 25].
10. Maximum Likelihood Sequence Detection (MLSD) technique, Differential Phase Shift Keying modulation, error control coding, usage of Multiple Input Multiple Output (MIMO) transmitters and receivers, applying appropriate power, combination with RF communication called Hybrid FSO-RF technology, spatial and wavelength diversity techniques, help in compensation of attenuation and loss of signals due to atmospheric turbulence [2, 5, 9, 11, 12, 15, 22, 24, 28, 31, 33].
11. FSO also has the advantages of license-free operation and insensitivity to electromagnetic interference, jamming and wiretapping [6, 9, 10, 11, 14, 17-23, 25, 26, 27, 30, 31, 32].
12. Many research and developments are going on beyond conventional FSO systems, and the new systems provide higher data speed (at terabits per second) using the same wavelength, decreasing divergence of beams and wavelength multiplexing techniques [7, 25, 27, 30, 31].
13. FSO communication is invisible and non-hazardous [18, 31].
14. Absence of side lobes and high directivity is another advantage of Free Space Optics [18, 22].
15. FSO also have underwater operation facilities [31].

DISADVANTAGES

1. Scattering, dispersion, absorption are the main limitations of FSO systems [3, 16].
2. The system faces major problems in cloudy and turbulent weather [5].
3. Attenuation and fluctuation of optical signals at receiver occurs due to outdoor disturbances [8].
4. BER (Bit Error Rate) value varies due to interference of atmospheric turbulence. [11]
5. Attenuation due to rain, snow, haze and fog, effect the most on FSO system [13, 14, 16, 22].

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6. Beam dispersion, atmospheric absorption, rain, fog, snow, interference from background light sources (including the sun), shadowing, scintillation, pointing stability in wind, and pollution are the reason of fading of signal and channel in FSO system [18, 25].
7. Flying birds, tall buildings, trees can temporarily block a single beam of light if it appears in line of sight (LOS) of transmission of FSO system [23].
8. Geometric losses also can be induced due to the spreading of beam and they can reduce the power level of the signal during travelling from one end to another [23].
9. Window attenuation is another is another disadvantage of FSO system [28].
10. Besides atmospheric turbulence, there is another major problem named PAT (Pointing, Acquisition, and Tracking) technique, which happens because of its unguided narrow beam propagation through the free space [30].
11. Safety for eyes and skins are not taken during radiation explosion of strong light [31].

APPLICATIONS

FSO systems are used in several fields which are as follows: -

1. To extend metropolitan area networks by connecting new fiber rings to the ones that already exists [4, 6, 23].
2. To access network (called last mile) which connect end users to Internet or service providers or to high speed networks [4, 6, 18, 23, 25].
3. To set new services which provide temporary infrastructure while the optical fiber cables are installed [4].
4. Act as a backup for an optical fiber system [4, 6, 23, 25].
5. Provide temporary connectivity which are required in fairs, exhibitions, emergency or calamity situations [4, 17, 18, 26].
6. Used to access network for isolated premises [6].
7. Used in high speed LAN to LAN and even in chip to chip connections [6].
8. Used in under sea and space communications [6].
9. FSO system can connect multiple buildings in corporate and campus networks that supports ultra-high speed without any cost of fiber optic connections [17, 18, 23].
10. FSO technology stand out powerfully to support high quality video transmission [17].
11. FSO is required for the growing number of bandwidth-intensive mobile phone services [17, 18, 26].
12. FSO links are used as a versatile alternative for security purposes where the fiber optic implementation is costly or infeasible [17, 18, 26].
13. FSO links provide the necessary high quality transmission and help in broadcasting live events such as sports, ceremonies from remote areas and war zones [17, 26].

CURRENT REASEARCH GOING ON

Research is going on optical wireless communication in different fields. Some of them are stated below: -

1. Short range optical wireless communication applications on phones that can charge and receive data with light in smartphone [34].
2. Ultra long range optical wireless communication finds application in NASA's Lunar Laser Communication Demonstration (LLCD) which transmit data from lunar orbit to Earth at rate of 622Mbps [34].
3. Research is going on to demonstrate 10Mbit/s transmission with Polymer Light Emitting Diodes or OLED with the help of optical wireless communication [34].
4. Recent researches are going on to build an underwater Wireless Sensor Network based on optical communication [35].

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5. Presently researches are going on to develop optical wireless communication using Silicon-On-Insulator Technology. This will allow low cost, mass producible and light weight components [36].
6. Optical wireless communication is currently researched to develop the next generation mobile network 5G [37].
7. One of the popular recent researches based on optical wireless communication is the night vision binocular and goggles which will transfer data from the optical device up to server by wireless communication. This ability is very important for military, law enforcement and private security services [37].
8. Major research on optical wireless communication is going on to improve transmission speed with different modulation formats which will suit optical communication [37].

FUTURE SCOPE

1. FSO can be used as an alternative or upgrade add-on to existing wireless technologies when the climatic conditions permit its full usage [6].
2. This can be also used in implementing universal connection among all smart home appliances like AV home appliances, white goods etc. [7].
3. This technique is ready for satellite links. [8]
4. OFDM-QPSK set-up is new solution for next generation FSO systems [11].
5. Improved coding technique can make development in optical FSO system in future [12].
6. FSO can be used as powerful complementary technology in RF wireless systems in the world of heterogeneous network system [17].
7. It can provide high speed data and large capacity requirements for upcoming communication market [22].
8. OFDM-FSO, WDM-FSO based systems will be made to improve the functionality [23].
9. As the atmospheric turbulence affects the intensity of the system, FSK and PPM can do better than OOK, and can be used in future [24].

CONCLUSION

From all the above discussions, we have been acquainted that free space optical communication is an emerging technology for transmission of optical signal through laser or light using line of sight propagation path which offers so many advantages over existing technologies like low cost and setup time, high bandwidth and no spectrum licence. The main inconvenience in this system is atmospheric attenuation and turbulence which can be mitigated by calculating the coefficients, selecting appropriate wavelength, transmission medium, modulation techniques, characterizing FSO channels and designing the FSO system properly. In this review paper, we have made a literature survey on many reference journals, thesis and review papers based on different topics on FSO. Finally, we note down many of the required equations, working principle with necessary diagrams, advantages, disadvantages, applications of the free space optics.

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